Response to the CARB ZEV Expert Panel Position on Lithium-Ion Full-Performance Battery Electric Vehicles

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Overview

This document provides a rebuttal to the CARB ZEV Expert Panel's position on the market potential for lithium-ion full-performance battery electric vehicles (Li-Ion FPBEVs).

The Expert Panel assessed the mass-market potential of Li-Ion FPBEVs based on the current status of the technology, as well as automotive OEMs' and battery suppliers' research, development, demonstration and marketing efforts. They concluded that Li-Ion batteries had good potential to meet all performance requirements of small, midsize and large FPBEVs as well as meeting cycle life goals. However, they argued that Li-Ion FPBEVs were still handicapped by their high battery costs and low customer acceptance due to limited range and long recharge time. They also suggested that no large-scale OEMs or battery developers were pursuing commercial FPBEV technology. The Panel therefore concluded that market development for Li-Ion FPBEVs had stalled and that, despite impressive technical advancement, the mass market potential of Li-Ion FPBEVs was still inherently limited. In short, they judged that Li-Ion FPBEVs were not a legitimate ZEV candidate technology for mass market penetration.

However, the Panel failed to acknowledge the healthy growth in niche FPBEV markets that can tolerate the cost, range and charging time of Li-Ion FPBEVs. This is exemplified by products from Tesla Motors and other emerging OEMs such as TH!NK. In combination, these niche markets provide a significant volume and pathway to mass market readiness, as well as propelling high-energy Li-Ion batteries much further along the R&D trajectory.

Furthermore, the expert Panel did not subject competing ZEV technologies (i.e. fuel cells) to the same stringent criteria for mass-market viability as they did FPBEVs, thereby injecting a significant technology bias in the comparison and results. Li-Ion FPBEVs are arguably much closer to mass-market readiness than other ZEV technologies when compared from a technology-neutral standpoint.

Overall, Tesla Motors feels that the Expert Panel failed to acknowledge the near-term market potential for Li-Ion FPBEVs and the tremendous progress of emerging OEMs in bringing these vehicles to market. Tesla Motors believes that Li-Ion FPBEVs deserve more recognition as a legitimate ZEV technology with rapidly-growing mass-market potential.

Commentary on Specific Aspects of the Expert Panel Report related to Li-Ion FPBEVs

The Expert Panel Report contains several specific observations regarding the viability of Li-Ion FPBEVs. Tesla Motors has provided a targeted response for each item, citing relevant data from its technology and business plans as well as public information from its competitors.

1) High energy Li-Ion technology has good potential to meet all performance requirements of small, midsize and larger FPBEVs with batteries of modest weight.

Tesla response:
We agree. Tesla's Energy Storage System (ESS) [1] is very close to meeting all of the DOE energy storage requirements for a FPBEV (Table A). Similarly, Tesla's technology competitors are nearing the achievement of this technical milestone (Table A). Note that the DOE FPBEV requirements are to enable mass-market BEVs with full functional equivalence to conventional vehicles, but this does not preclude early market penetration with batteries of lesser performance.

Table A: Specifications for Li-Ion FPBEV battery packs under development

Vehicle	Battery Supplier	Type	Energy (kWh)	Peak Power (kW)	Weight (kg)	Specific Energy (Wh/kg)	Specific Power (W/kg)
FPBEV	*DOE goal*[1]	*n/a*	*25-40*	*50-100*	*250*	*100-160*	*200-400*
Tesla Roadster	**Tesla Motors**	**Li-Ion**	**53**	**230**	**450**	**118**	**511**
TH!NK City	A123 Systems[2]	Li-Ion	19	no data	260	73	no data
	EnerDel[2]	Li-Ion	26	no data	260	100	no data
n/a	JCS[1]	Li-Ion	24	55	265	90	210
n/a	GAIA[1]	Li-Ion	22	50	200	115	250
n/a	LitCel[1]	Li-Ion	20	155	170	118	912
n/a	Lamilion[1]	Li-Ion	9.2	62	150	60	400
n/a	Kokam[1]	Li-Ion	30	130	265	110	490

[1] Data extracted from Tables 3-2 and 3-6 of the Expert Panel Report
[2] Data reported by Green Car Congress [11]

2) Cell and battery technology designed for these applications are likely to also meet cycle life goals.

Tesla response:
We agree. Unfortunately, Tesla Motors is unable to disclose proprietary data for the cycle and calendar life of the Li-Ion cells in the Tesla Roadster. However, Tesla will provide a warranty on its powertrain including the ESS. Furthermore, as Li-Ion technology continues to advance, Tesla expects there will be strong consumer demand for battery upgrades, which may obviate the perceived need for extended battery life and/or warranty coverage.

3) No efforts are underway to advance battery technology for FPBEV applications – not by large-scale battery developers nor major automotive OEMs.

Tesla response:
We disagree. There has been a spate of recent announcements from both automotive OEMs and major battery developers that directly contradict this observation. These include:

- Nissan's announcement that it will launch an electric car in the US in 2010 [2]
- The announcement of a joint venture between Nissan-Renault and Project Better Place to roll-out mass-market FPBEVs with supporting infrastructure in 2011 [3].
- NEC's announcement of a joint venture with Nissan to develop and market lithium-ion batteries for wide-scale automotive application by 2009 [4]. NEC was also previously linked to Subaru in the development of Li-Ion batteries for FPBEVs.

- Subaru's announcement that it wants to "*become the leading brand in the electric vehicle market*" as evidenced by field trials of its R1e and G4e concept car, for which it has stated it will commence production as early as 2009 [5].
- Mitsubishi's business plan to launch a production version of its iMiEV in 2010 [6].
- Mitsubishi's formation of a joint venture with GS Yuasa for the development, manufacture and sales of large lithium-ion batteries for FPBEVs [6].
- The announcement by Panasonic EV Energy Co, the battery-making joint venture between Toyota and Matsushita, that it is developing plans for mass production of high-energy lithium-ion batteries [7].
- Daimler's announcement of a market trial of its Smart EV – an electric variant of the popular Smart fortwo – which it hopes to produce in 2010 [8].

In addition, there has been a surprising emergence of new contenders in the Li-Ion FPBEV battery industry, all of whom are investing in the future volume production of Li-Ion FPBEVs:

Automotive OEMs:
- Tesla Motors
- TH!NK
- Phoenix Motorcars
- Miles Automotive

Battery suppliers:
- Johnson Controls / SAFT
- Lithium Technology Corporation (a.k.a. GAIA)
- Kokam
- EnerDel (a joint venture between Deplhi and Ener1)
- A123 Systems

In the words of the Panel:

> "*…[these companies'] strategy is pursuit of limited-volume applications and markets that may be emerging, especially in small Battery Electric Vehicles (BEVs) (including FPBEVs) and more recently also in PHEVs. Several of these companies hold the view that Li Ion-powered PHEVs and small BEVs will be able to attain life cycle cost competitiveness with conventional vehicles in urban fleet applications, and a few have established cell production capacities for hundreds to a few thousands of 10-25kWh batteries per year, sufficient for demonstration fleets… Several of these manufacturers noted that development of such technologies was likely to benefit from supported demonstration programs and/or financial incentives."*

Finally, observation 3) fails to recognize the technology-forcing role played by the ZEV Regulation. There has been a strong correlation between the technology bias of the ZEV Regulation and the resulting OEM investment. The existing ZEV Regulation provided little incentive for the development of FPBEVs, and so the R&D effort shifted away accordingly. Li-Ion FPBEV R&D and marketing efforts would be much further advanced if the ZEV Regulation had recognized the near-term potential for this technology by including appropriate requirements and incentives.

4) Battery costs remain high in mass production, and are in excess of expected lifetime fuel cost savings.

Tesla response:
Irrespective of whether this observation is true or not, we feel it is misleading since it reflects the Panel's preconceptions of how the market perceives the costs and benefits of FPBEVs.

Firstly, there is significant evidence to suggest that ZEV buyers do not assess the value proposition in this way, which makes the Panel's "payback" criteria inappropriate and arguably irrelevant. For example, research by Turrentine [9] has found that green car buyers are far more motivated by themes of sustainability in the vehicle attributes, or impressive efficiency metrics (such as high MPG), rather than by "payback" economics.

Secondly, the battery cost goals determined by DOE for FPBEVs (Table 3-4 from the Panel Report) were intended to enable cost parity with conventional vehicles since this criterion was perceived to be necessary for mass market adoption. However, there are segments of the market that will absorb higher battery costs, such as the premium vehicle segments targeted by Tesla Motors. Alternatively, there are business models that allow consumers to amortize battery costs over the vehicle life (e.g. TH!NK, Project Better Place).

Lastly, it should be noted that no such "payback" criteria was applied to the other candidate ZEV technology (i.e. fuel cell vehicles). Had this criterion been applied, the prohibitive cost of fuel cells and hydrogen tanks and uncertain cost of hydrogen fuel would not have been conducive to a favorable outcome.

Table 3-4. Battery Cost[1] Goals

Vehicle Type	Battery Rating	Production Rate (Batteries/year)	Specific Capacity Cost[2] ($/kWh)	Specific Power Cost [3] ($/kW)
FPBEV	40 kWh	25k	<150 [< $6,000]	n.a.
HEV	25--40 kW	100k	n.a.	<20 [< $500 – $800]
PHEV	(10 kWh)	(100k)	(<300) [< $3000]	n.a.

[1] selling Price to OEMs
[2] in brackets: cost goals for complete batteries of rated energy storage capacity
[3] in brackets: cost goals for complete batteries of rated peak power capability

5) Batteries assembled from laptop cells are being used in FPBEVs fabricated on a small scale, but these have inherently high costs and uncertain calendar and cycle life.

Tesla response:
Tesla Motors ESS production is more than a "small-scale fabrication". Our facilities will produce many thousand batteries per year, both for ourselves and other OEMs. In addition to Tesla's production volume of >1000 cars per year (>55 MWh/year), Tesla is also negotiating battery supply agreements with at least two other FPBEV OEMs that will substantially boost its ESS production volumes.

At present, small-cell packs have substantially lower costs than large-cell packs, as well as a mature supply base, providing a near-term pathway to market. Small cells are available at commodity prices of ~$300-350/kWh from multiple large-volume cell vendors, compared to large-format cells which are only available in limited quantities at substantially higher costs (>>$500/kWh module cost). Small cells are also on a rapid technology development trajectory, as shown in Figures A and B. There is certainly some extra cost overhead in integrating small cells into a large capacity battery pack, but at present, the balance still favors small cells and Tesla Motors will continue to source these cells while their economics remain favorable.

Battery Energy Density Trend

Lithium Ion vs. Ni-MH vs. Ni-Cd

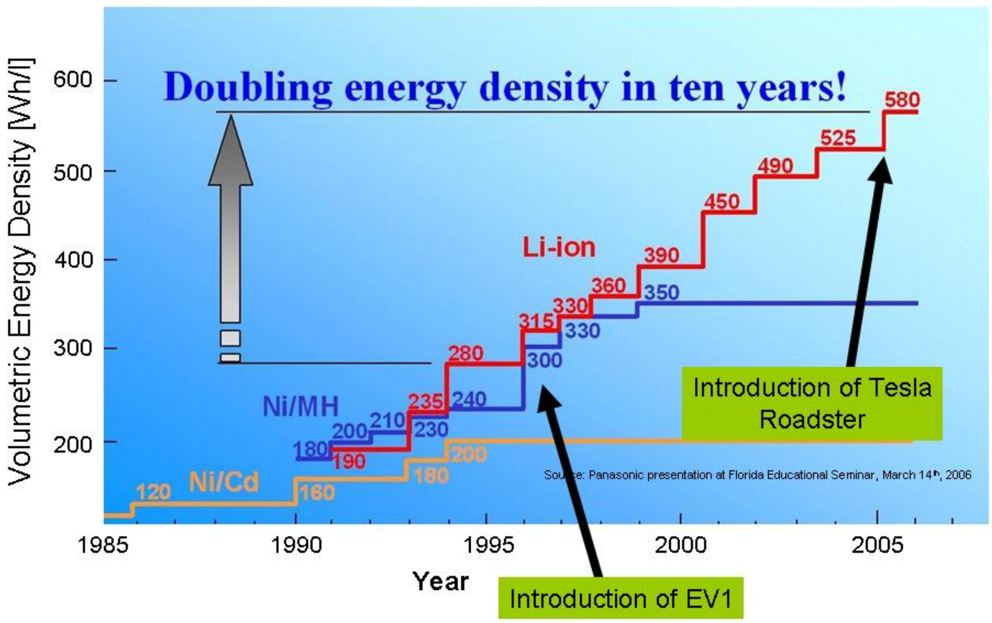
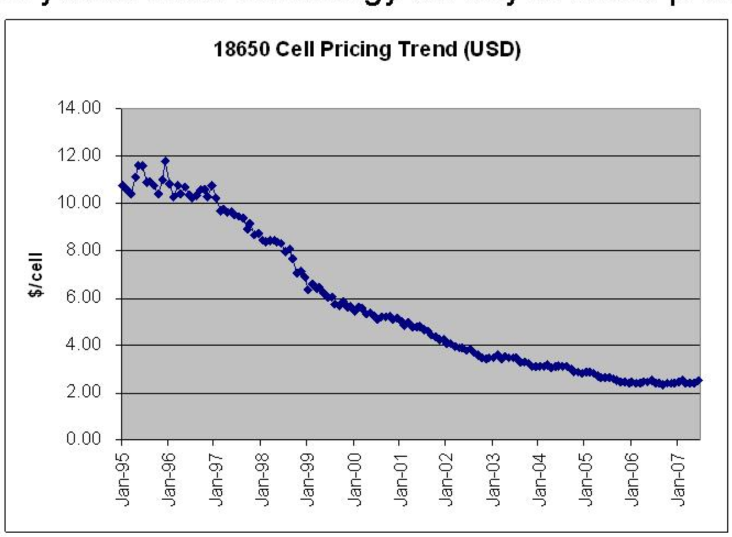


Figure A: Performance trends for consumer-grade high-energy Li-Ion cells.

Li-ion Battery Price Trend

Ten years: twice the energy density at ¼ the price



Source: Institute of Information Technology, September, 2007

Figure B: Pricing trends for consumer-grade high-energy Li-Ion cells.

Tesla uses computer-controlled and distributed charge and thermal management to keep cells within voltage and thermal limits designed to optimize calendar and cycle life. Tesla Motors has deliberately chosen to forgo some useable capacity in favor of cell longevity.

The small-cell approach also provides inherent system reliability, redundancy and safety characteristics.

- Tesla's ESS contains 6831 cells, arranged in 11 modules in series, with 9 "bricks" in series per module, and 69 parallel cells per brick. This design provides for graceful pack degradation since a single cell failure will only degrade performance by 1/69th, and probability dictates that the Tesla ESS can likely absorb multiple cell failures across the 99 bricks without compounded performance degradation.
- Passive current sharing between parallel cells means that the (healthiest) cells with higher capacity and lower impedance carry more of the current load.
- The highly modular design of Tesla's ESS allows for multiple layers of over-current and over/under-voltage protection at the brick, module and pack level.
- Smaller cells have a higher surface-to-volume ratio, which reduces challenges associated with effective thermal management. In particular, Tesla's ESS is designed to contain thermal runaway to a single cell and inhibit propagation.

6) Prior efforts to introduce FPBEVs were unsuccessful due to high manufacturing cost (primarily the battery) and limited mass market customer acceptance due to limited range and long recharge time, and there has been little progress since.

Tesla response:
There has been substantial progress. This was confirmed by GM Vice Chairman Bob Lutz while speaking at the 2008 Geneva Auto Show. As reported by the Wall Street Journal [10], Lutz told reporters that *"recent advances in lithium-ion batteries indicate that future electric cars might be able to travel 300 miles, or nearly 500 kilometers, before they need to recharge, making them much more practical as a mass-market product.*"

For example, Tesla Motors has successfully launched the Roadster with its FMVSS certification, 4-second 0-60mph acceleration, 120mph top speed, 227mi EPA range and 4hr home-recharge capability. The Roadster is competitively priced at $98,000 to compete in the premium, performance vehicle market segment and Tesla has taken more than 1000 reservations to date.

The high operating range and enhanced recharging capabilities of the Tesla Roadster provide a completely redefined user experience and utility for FPBEVs:

- The Roadster's high EPA range of 227mi is approximately double that of previous-generation FPBEVs such as the 2003 Toyota RAV4 EV (136mi) and 1999 GM EV1 (111mi). This high range allows motorists to commute and run multiple errands on a single charge each day without having to worry about recharging.
- The Roadster's dedicated 240V/70A home charging station provides a recharging rate (0.9mi per minute) more than double that achieved by dedicated 220V/30A chargers for the RAV4 EV and EV1 (0.4 mi per minute). Such high rates allow motorists to replenish a useful range within a reasonable time.
- The Roadster's 240V/40A mobile connector (0.5mi per minute) also exceeds the charging rate of earlier-generation systems but also enables access to the ubiquitous 220-240V electrical supply infrastructure present in many homes and businesses.

In combination, these advances in range and recharging greatly reduce the need for an extensive, dedicated FPBEV recharging infrastructure.

Throughout the industry, a number of established and emerging OEMs are also developing lower-range and lower-cost Li-Ion FPBEVs (some with fast-recharge capability) to compete in higher-volume segments of the market by 2010. These vehicles include:

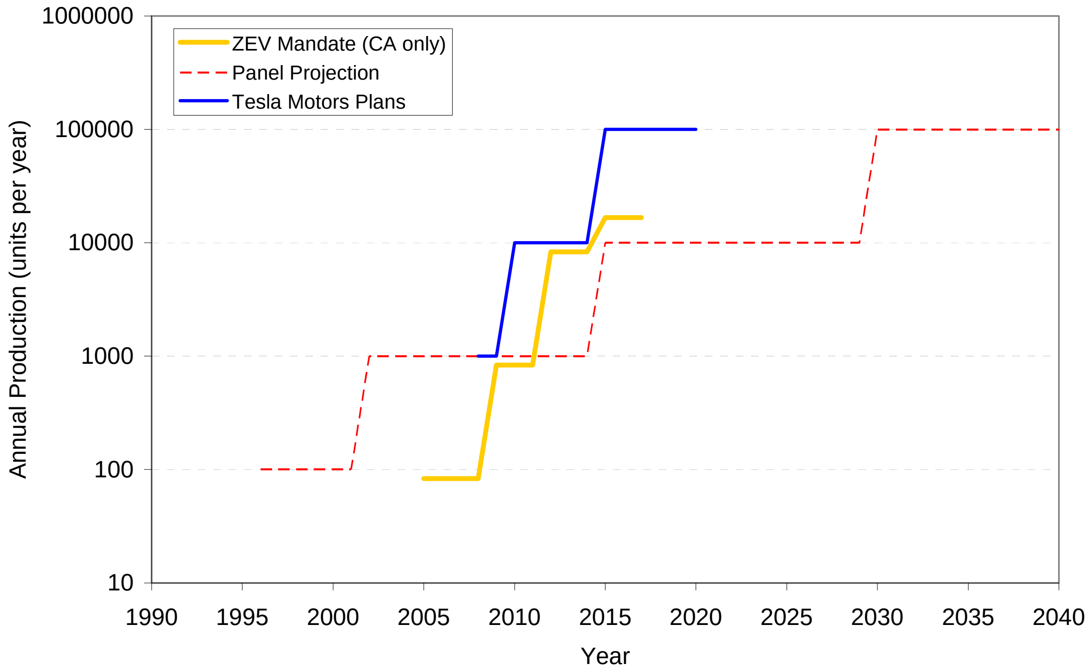
- TH!NK's City EV with 110mi range for US$30,000 with a US$300 per month battery service agreement
- Phoenix MotorCars' SUT/SUV models with 100mi range, 10min/95% fast charge and 3yr/36,000mi warranty
- Subaru's R1e with 60mi range, 8min/80% fast charge and a target price of US$17,500 in 2012. 40 Subaru EVs are currently under trial by employees at Tokyo Electric Power Co, with plans to increase the trial to 100 vehicles next year.
- Mitsubishi's i-MiEV with 100mi range. Ten of these vehicles are currently involved in a market trial with Tokyo Electric Power Co.
- Renault-Nissan's EV with 100mi range and fast charge capability for Project Better Place.
- Daimler's Smart EV with 72mi range, of which 100 are currently involved in a 4-year market trial in the UK.
- Miles Automotive's XS500 with 120mi range.

7) The bottom line question posed to the Panel by the ARB was "what is the approximate timeframe in which the Panel expects the various ZEV and ZEV enabling technologies to achieve the:
- ***Demonstration stage (100s of vehicles per year) = 1996***
- ***Pre-Commercialization (1000s of vehicles per year) = 2002***
- ***Early Commercialization (10,000s of vehicles per year) = 2015***
- ***Mass Commercialization (100,000's of vehicle per year) = 2030***

Tesla response:
We disagree with the Panel's projections. The chart below compares the plans of Tesla Motors with the Panel's projections and the ZEV Regulation requirements. Clearly, we expect FPBEVs to penetrate the market much faster than projected. Furthermore, Tesla Motors expects to exceed the ZEV Regulation requirement for pure ZEVs solely with its own volumes.

Lastly, it is important to reiterate that TH!NK, Phoenix Motorcars, Mitsubishi, Renault-Nissan, Smart and Subaru all have publicly-stated plans to launch FPBEV models within the next two years.

Various Scenarios for FPBEV Market Penetration



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